Image-to-Simulation Workflow for (Non)Continuum Fluid Flow in Woodford Shale Rock Matrix

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Acknowledgments

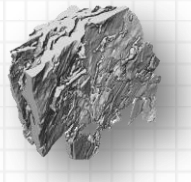
Outline

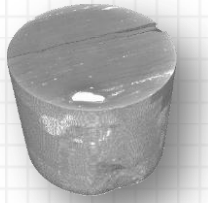
1) Correlative X-Ray and Electron Microscopy
- Micro X-Ray Microscopy (micro-XRM)
- Nano X-Ray Microscopy (nano-XRM)
- Focused Ion Beam Scanning Electron Microscopy (FIB-SEM)

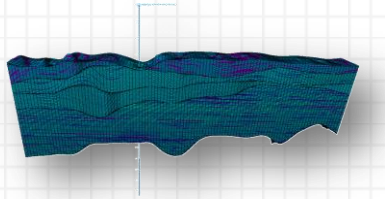
2) Digital Rock Physics (DRP)
- Image Prosessing and Segmentation
- Model Reconstruction and Visualization
- Pore/Fracture Network Modeling
- Mesh Generation for (Non)Continuum Fluid Flow Modeling and Simualtion

Rational and Significance

RESERVOIR QUALITY







PORE-SCALE CORE-SCALE RESERVOIR-SCALE

Multi-Scale Characterization of Heterogeneous Petroleum Geomaterials/Geosystems

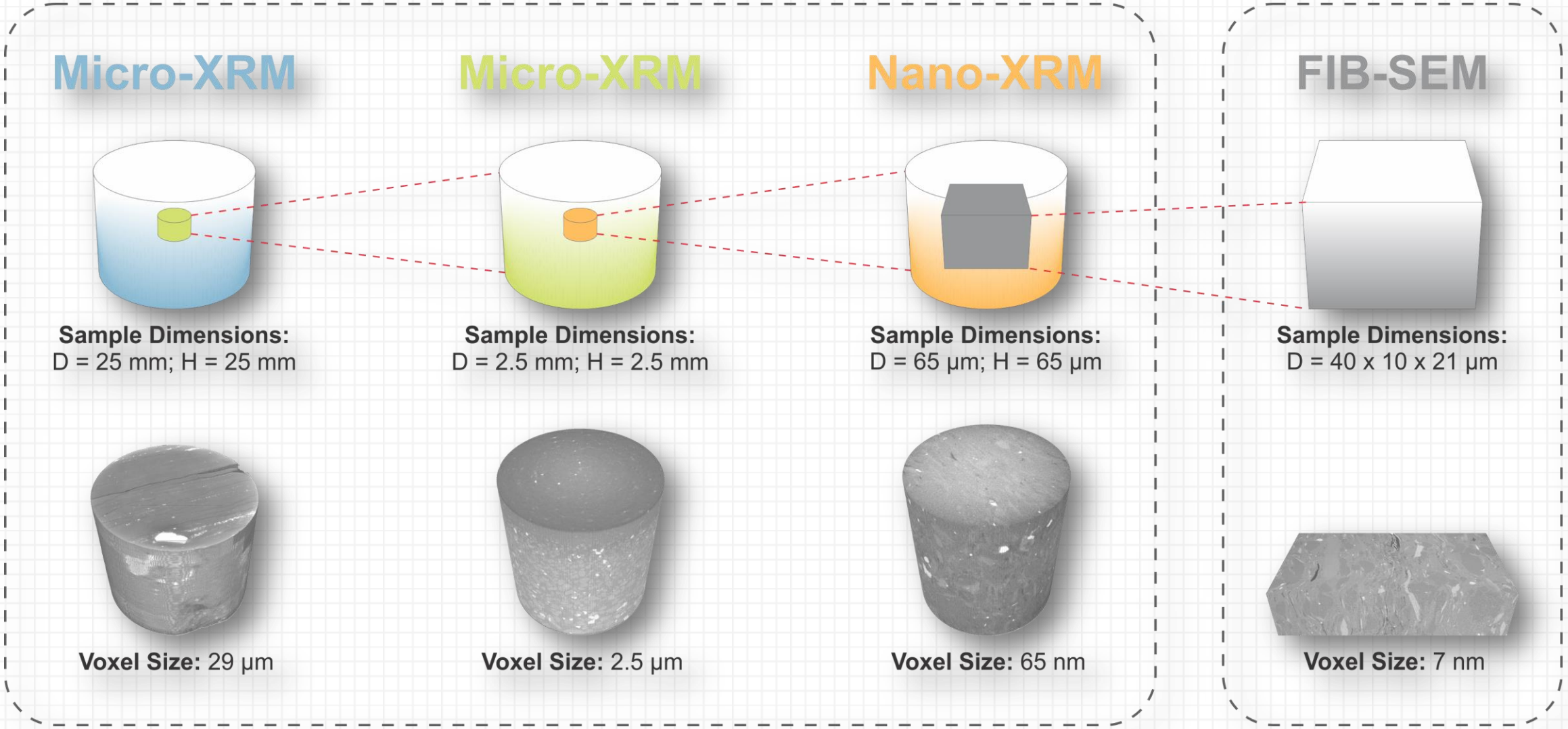
THERMO **HYDRO** **MECHANICAL** **CHEMICAL**

Experimental and Numerical Analysis of Coupled THMC Processes

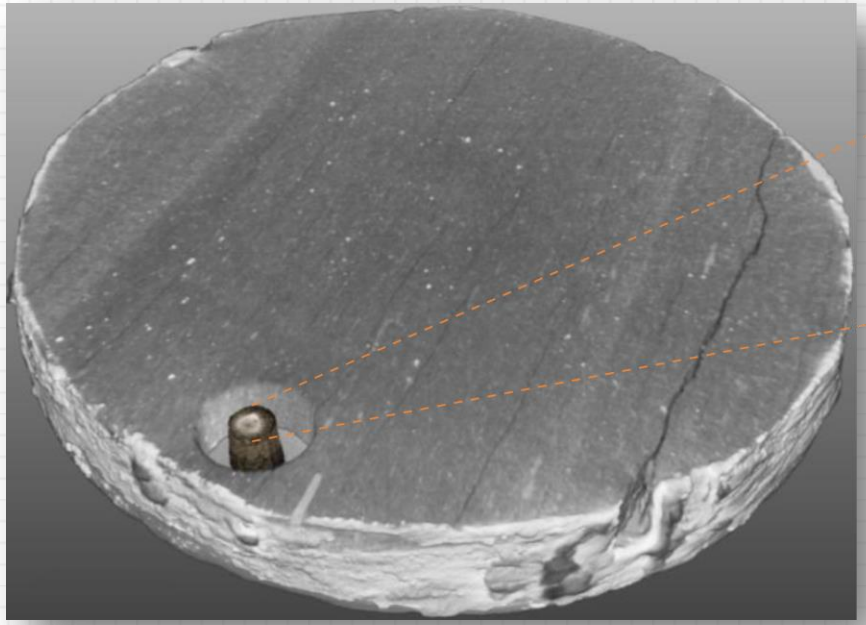
COMPLETION QUALITY

Correlative Microscopy

Correlative (X-Ray and Electron) Microscopy



Correlative (Micro and Nano) X-Ray Microscopy (XRM)

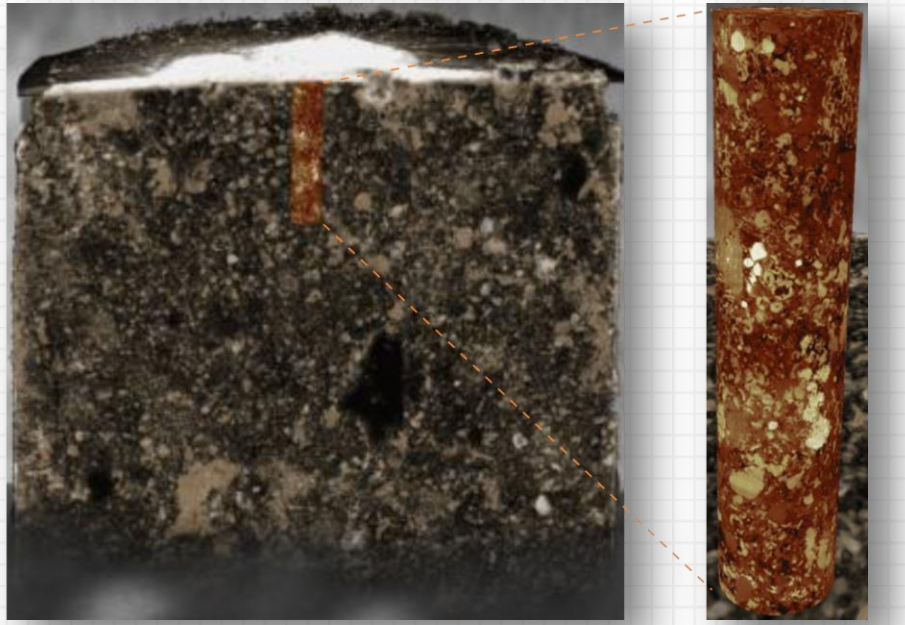


Micro-XRM

Micro X-Ray Microscopy
(25 um resolution)

Micro-XRM

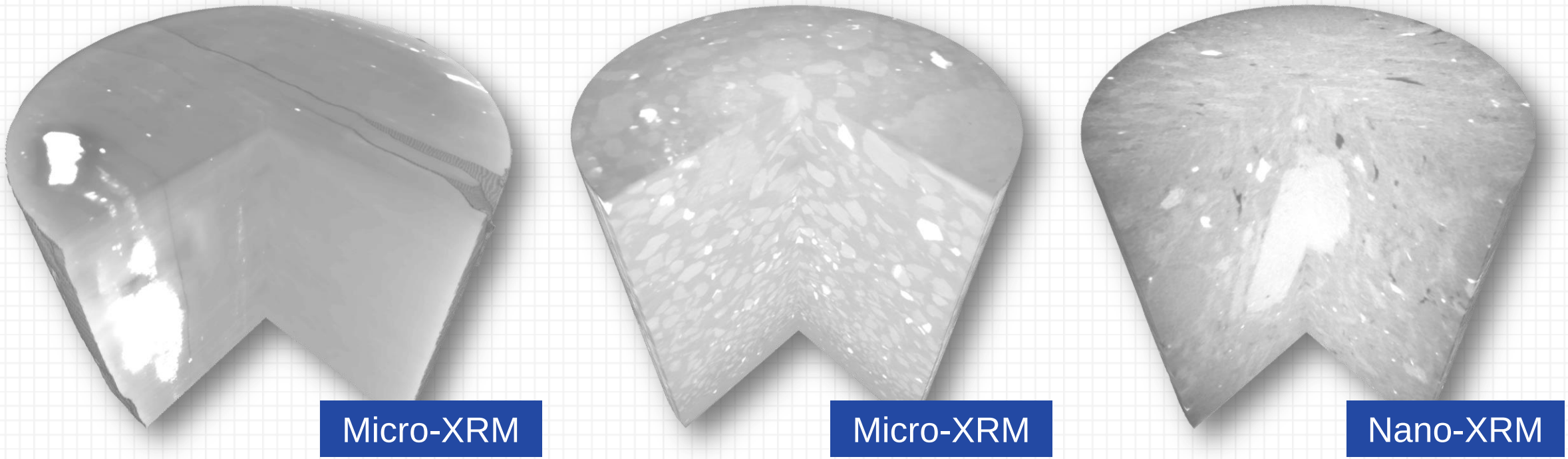
Micro X-Ray Microscopy
(2.5 um resolution)



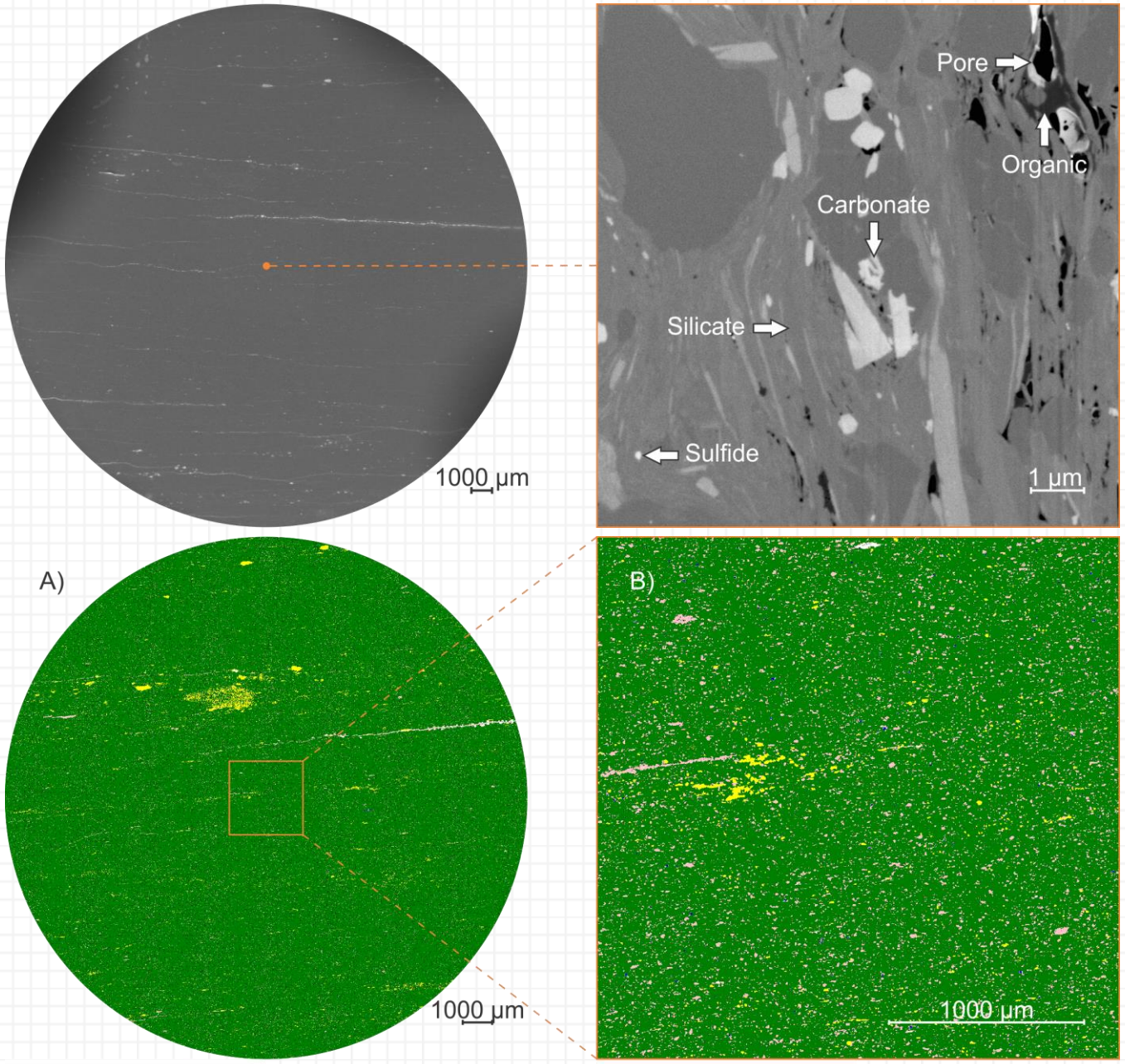
Nano-XRM

Nano X-Ray Microscopy
(150 nm resolution)

Correlative (Micro and Nano) X-Ray Microscopy (XRM)



- Although XRM models reveal the mineralized structure of Woodford Shale, they cannot fully resolve the pore network of the sample.
- However, micro-XRM and nano-XRM were found to serve as a useful bridge from pore-scale, reveled by FIB-SEM, to the core-scale.



Mineral Name	Area (%)
Feldspar	88.825
Quartz	8.691
Pyrite	2.392
Organic and/or Pores	0.205
Dolomite	0.092

Mineral Name	Area (%)
Feldspar	88.552
Quartz	9.917
Pyrite	1.425
Organic and/or Pores	0.381
Dolomite	0.106

Mineralogy

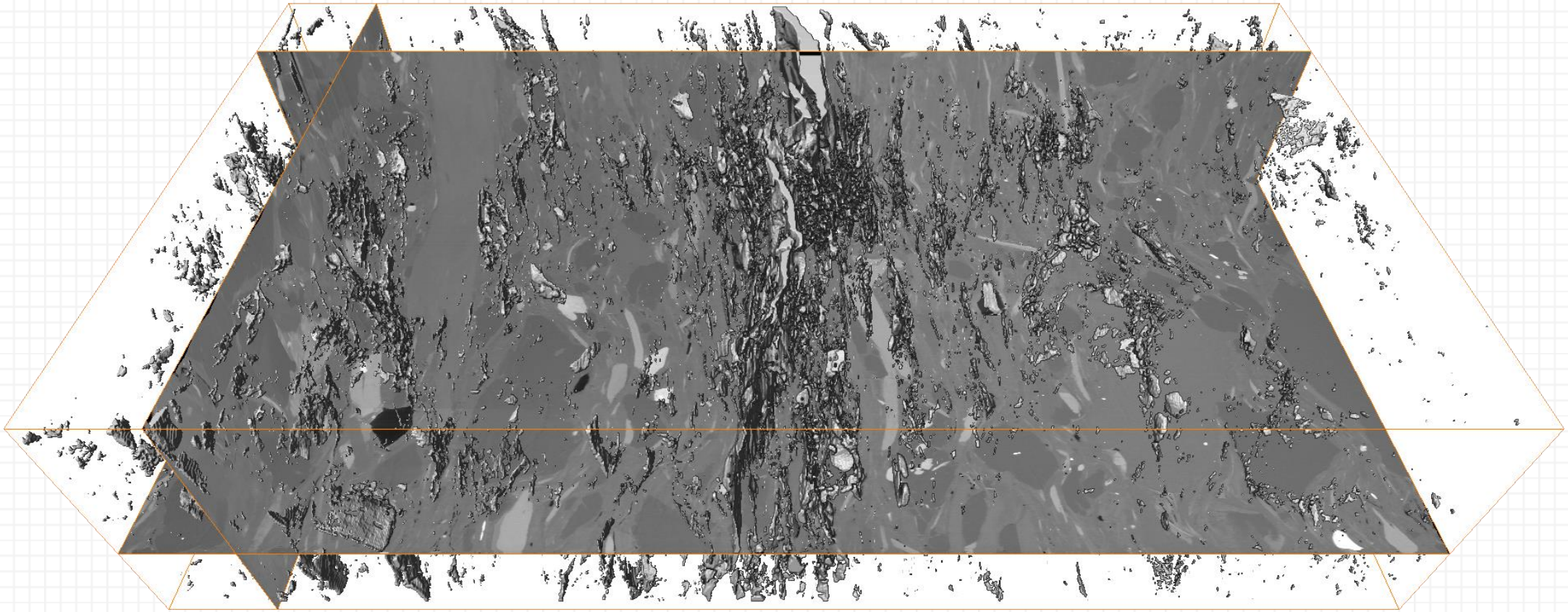
1) Scanning Electron Microscopy (SEM) image
2) Automated mineralogy and petrography (A) 10 um resolution and (B) 2 um resolution mosaic image

5 (non)organic phases:

- pores
- organic matter
- silicate (feldspar, clay, quartz)
- carbonate (dolomite)
- sulfide (pyrite)

Digital Rock Physics

Case Study: Woodford Shale

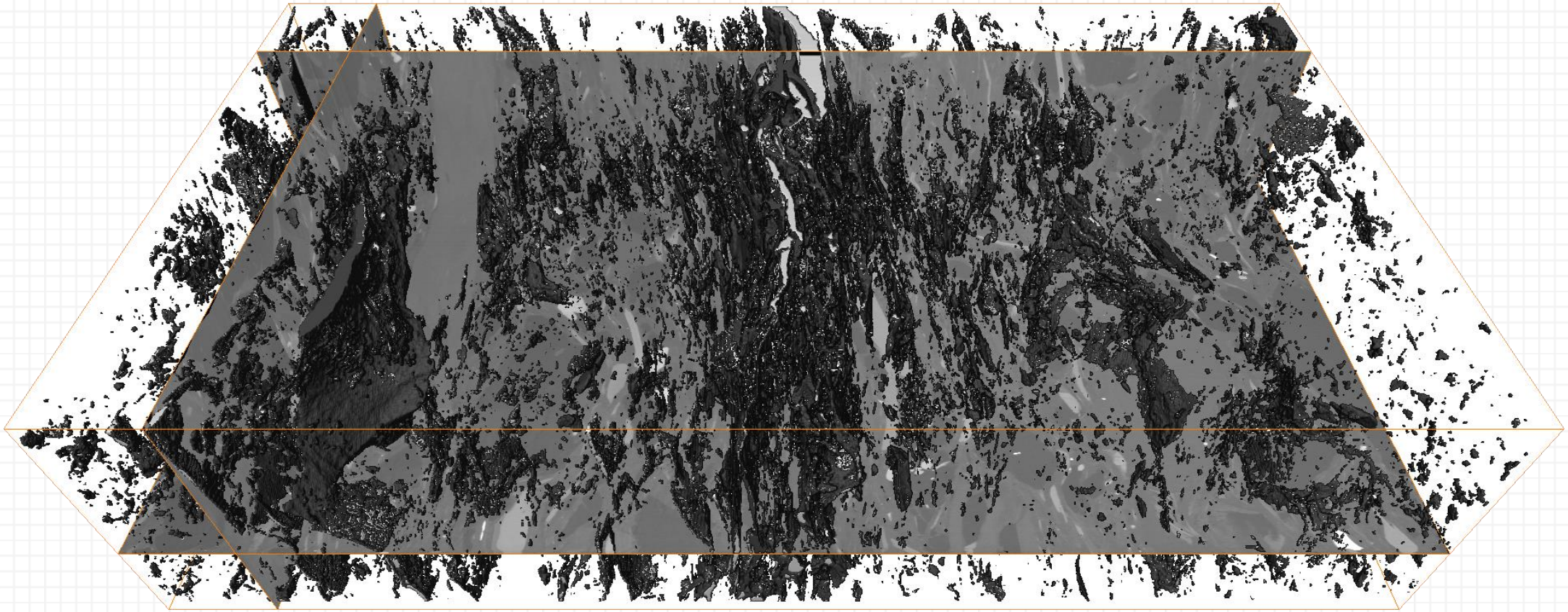


Pores

FIB-SEM

Focused Ion Beam Scanning Electron Microscopy

Case Study: Woodford Shale

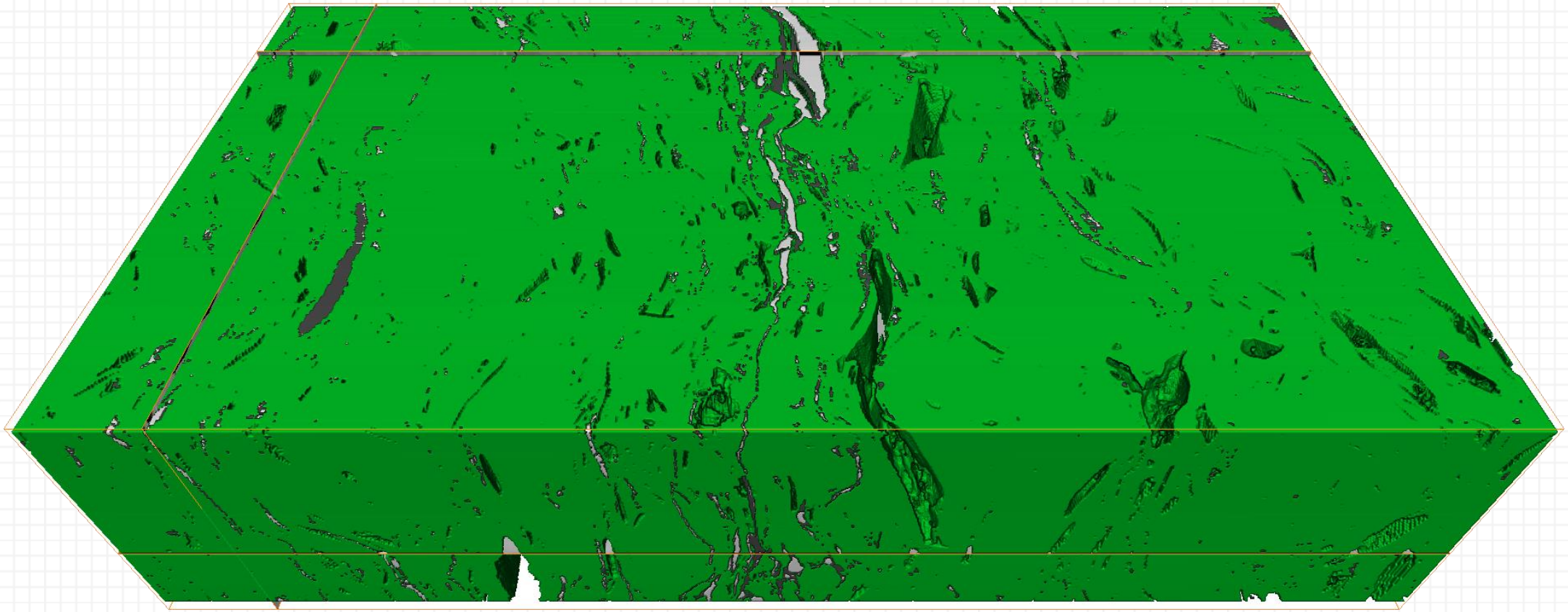


Pores + Organic Matter

FIB-SEM

Focused Ion Beam Scanning Electron Microscopy

Case Study: Woodford Shale

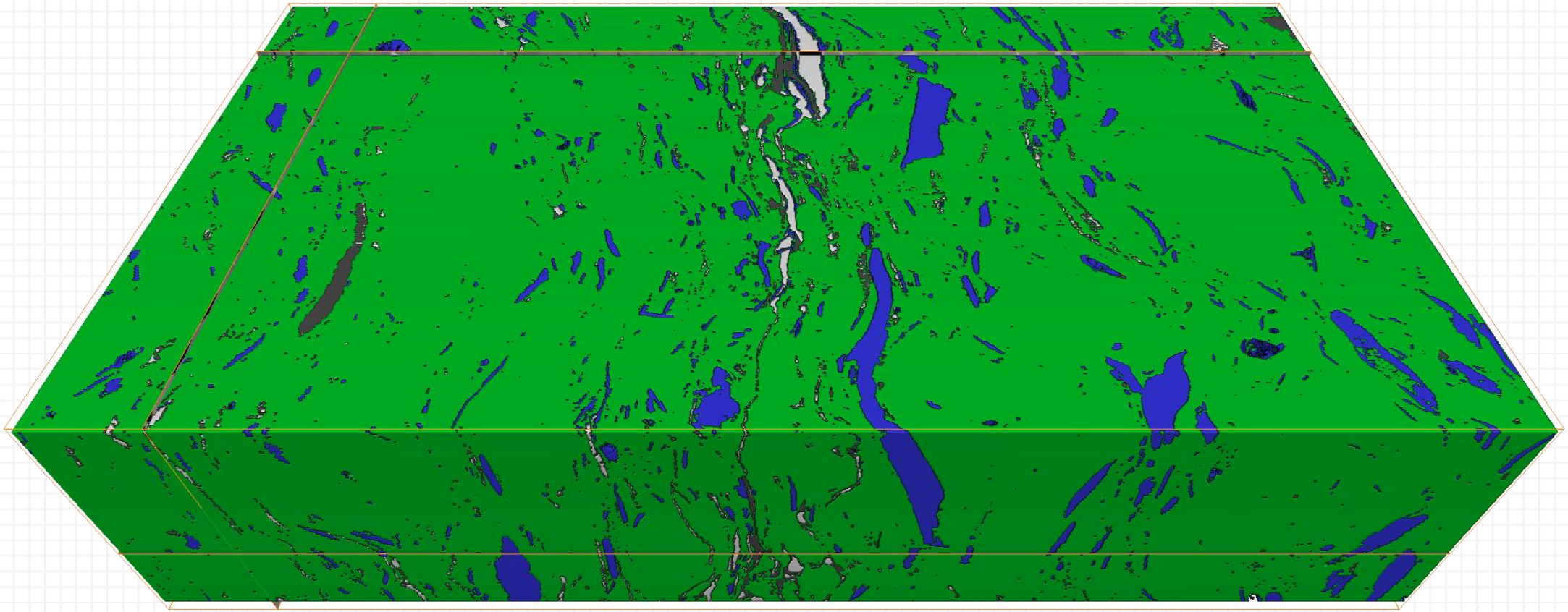


Pores + Organic Matter + Silicate

FIB-SEM

Focused Ion Beam Scanning Electron Microscopy

Case Study: Woodford Shale

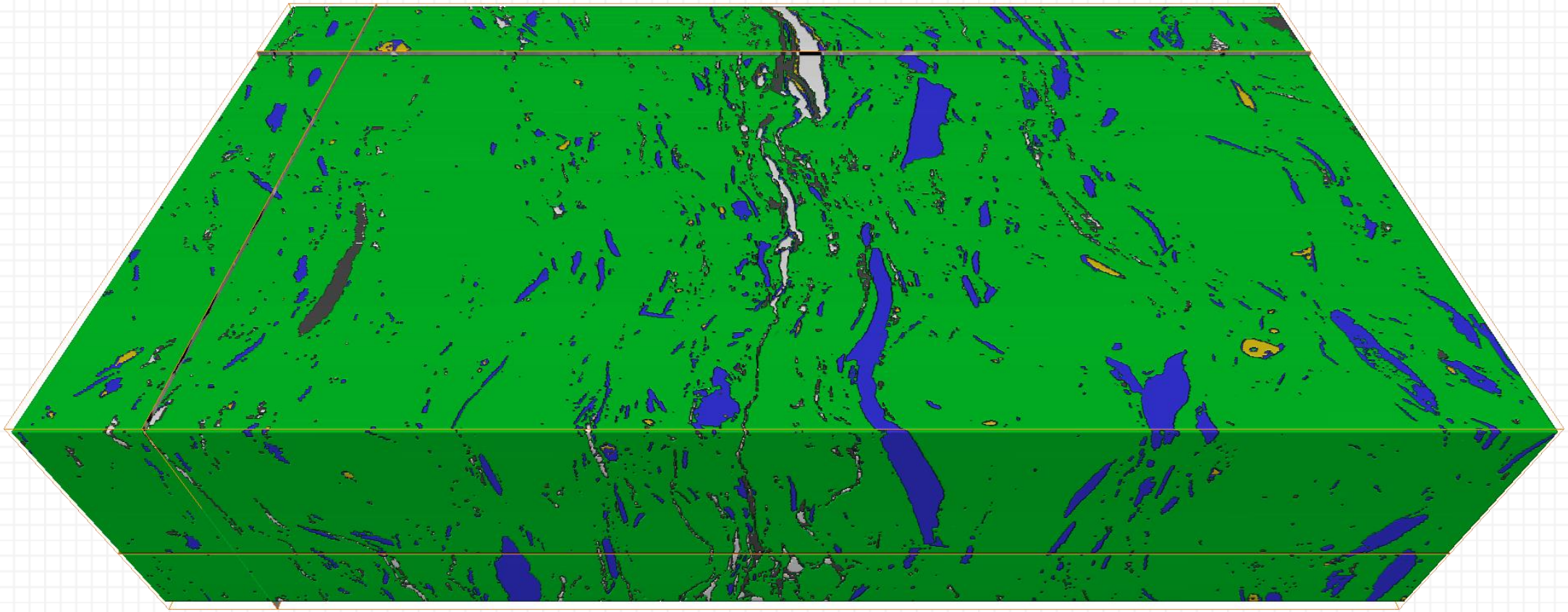


Pores + Organic Matter + Silicate + Carbonate

FIB-SEM

Focused Ion Beam Scanning Electron Microscopy

Case Study: Woodford Shale

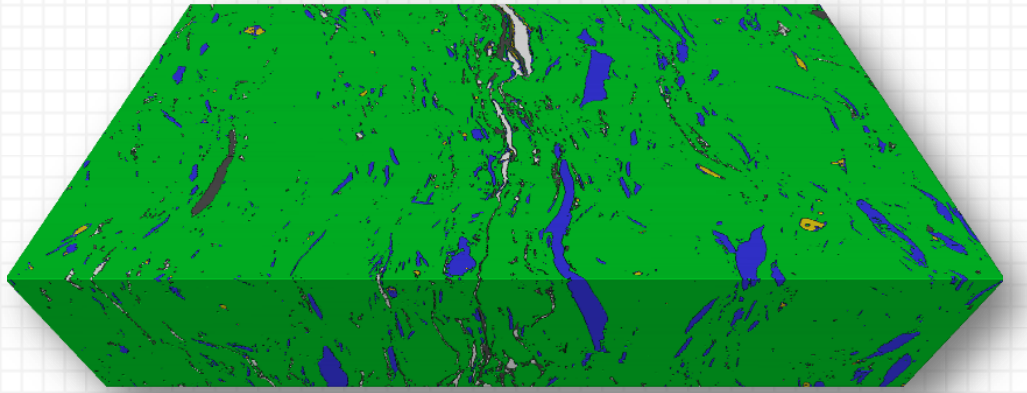


Pores + Organic Matter + Silicate + Carbonate + Sulfide

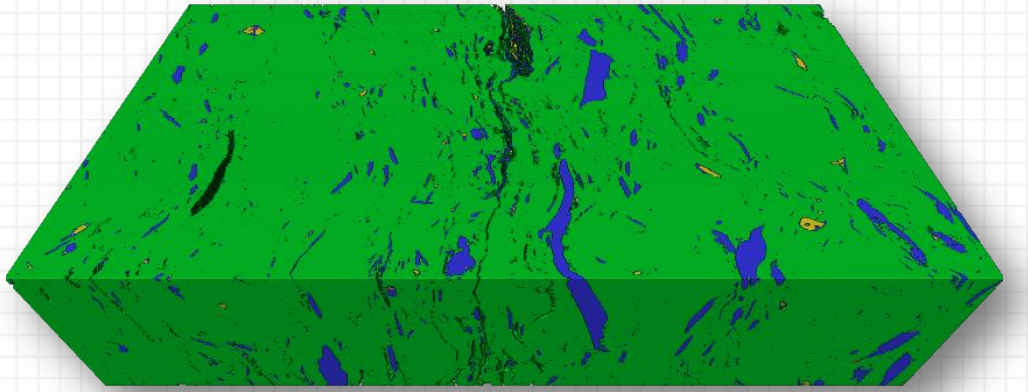
FIB-SEM

Focused Ion Beam Scanning Electron Microscopy

Organic vs. Nonorganic (Mineral) Matter

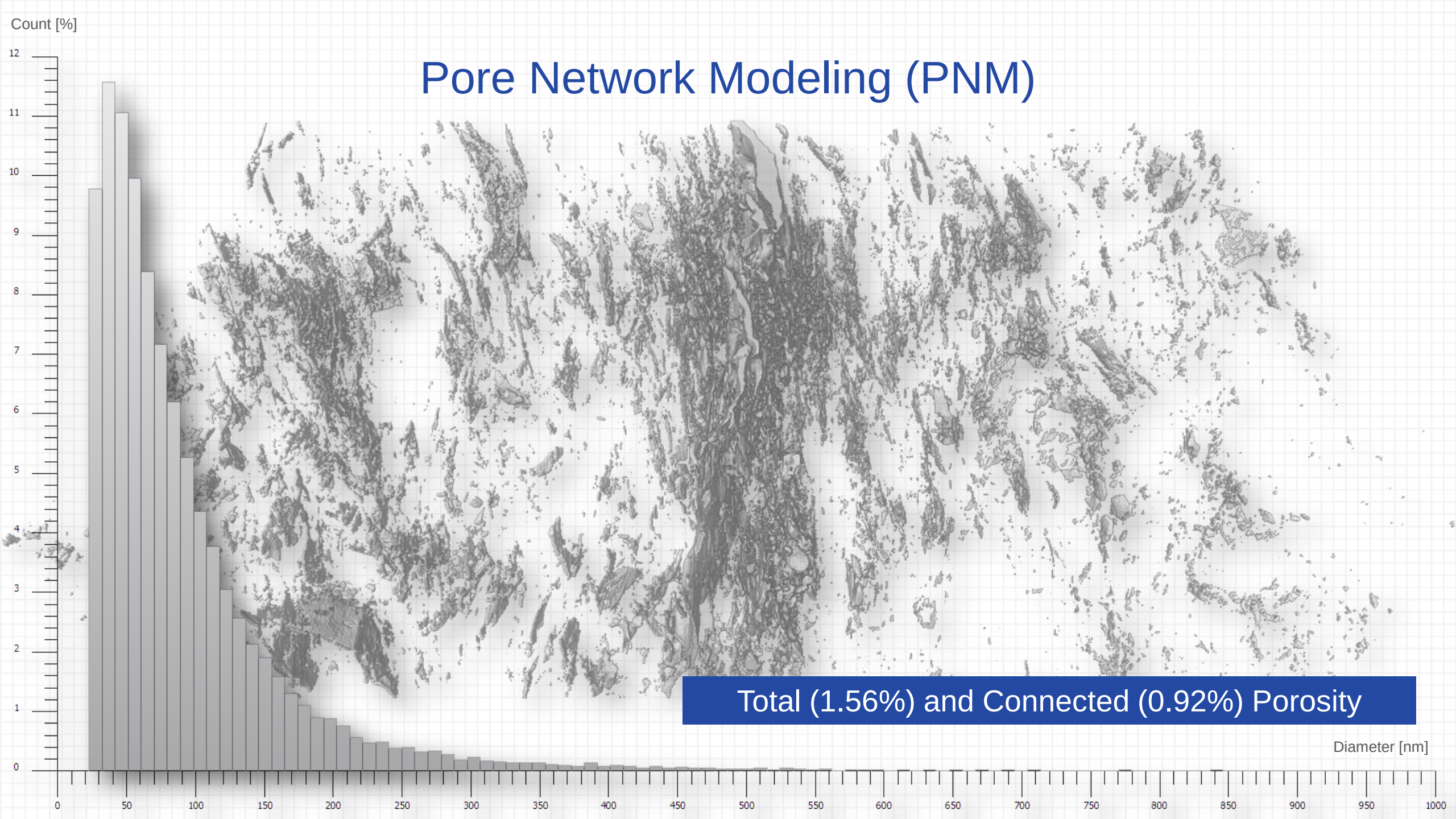


Organic Matter 2.69%



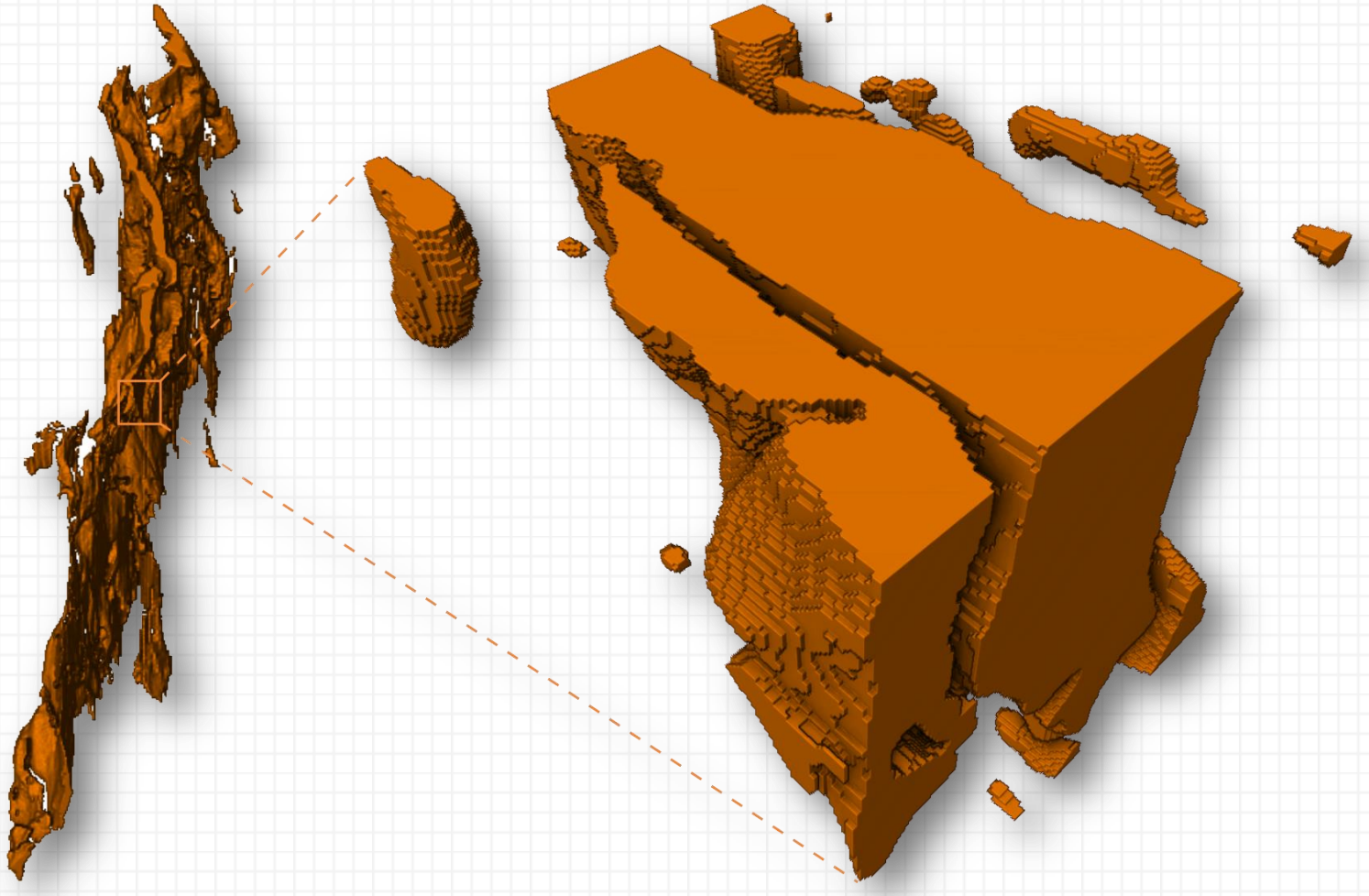
Nonorganic Matter 95.76%

Pore Network Modeling (PNM)



Total (1.56%) and Connected (0.92%) Porosity

Region of Interest (ROI)

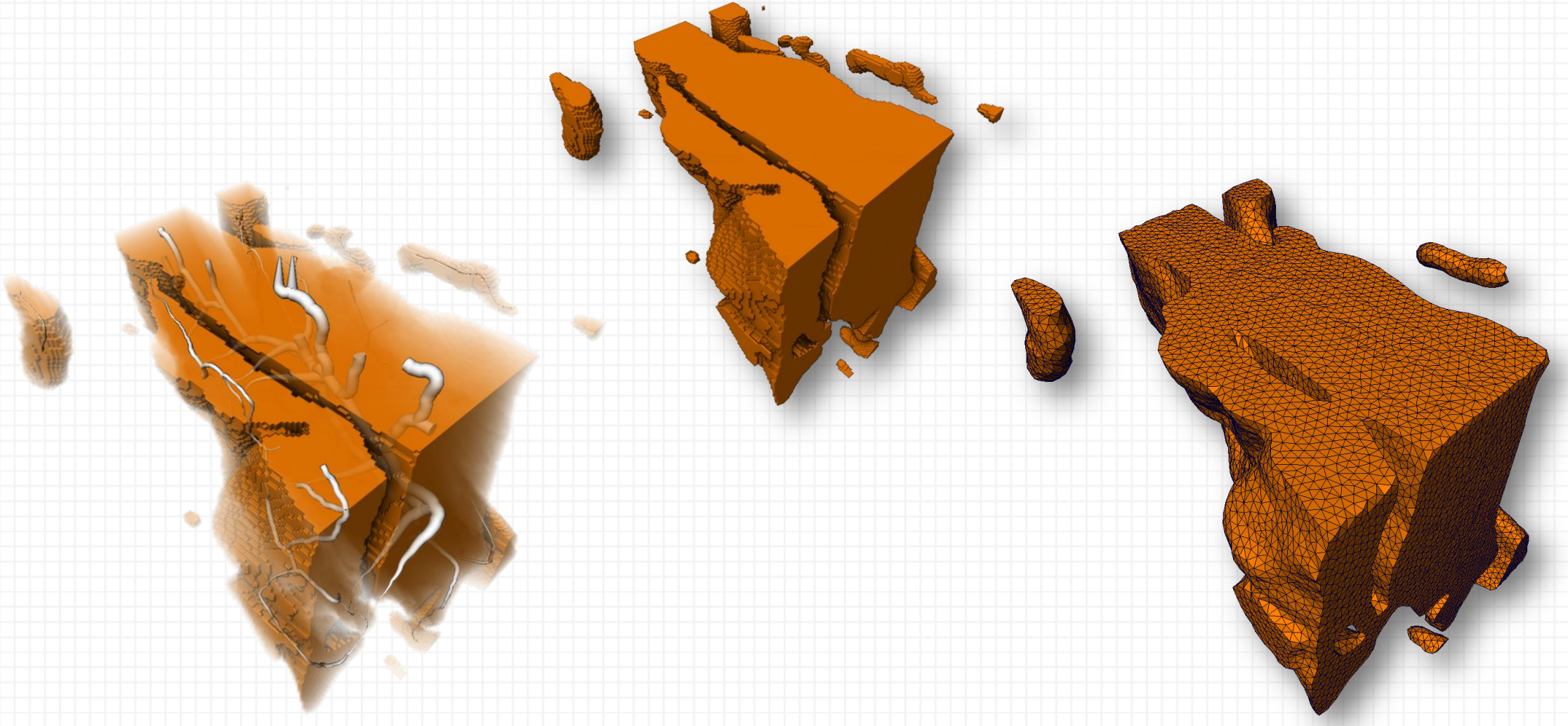


Connected Pore Network

Region of Interest (ROI)

Image-to-Simulation Workflow

Model Reconstruction and Visualization



Pore Network Modeling

Mesh Generation

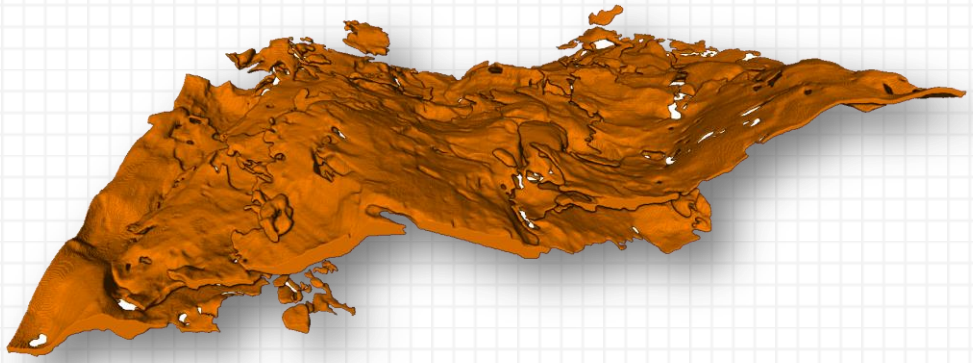
(Non)Continuum Fluid Flow in Porous Media

Continuum and non-continuum flow regimes based on Knudsen number:

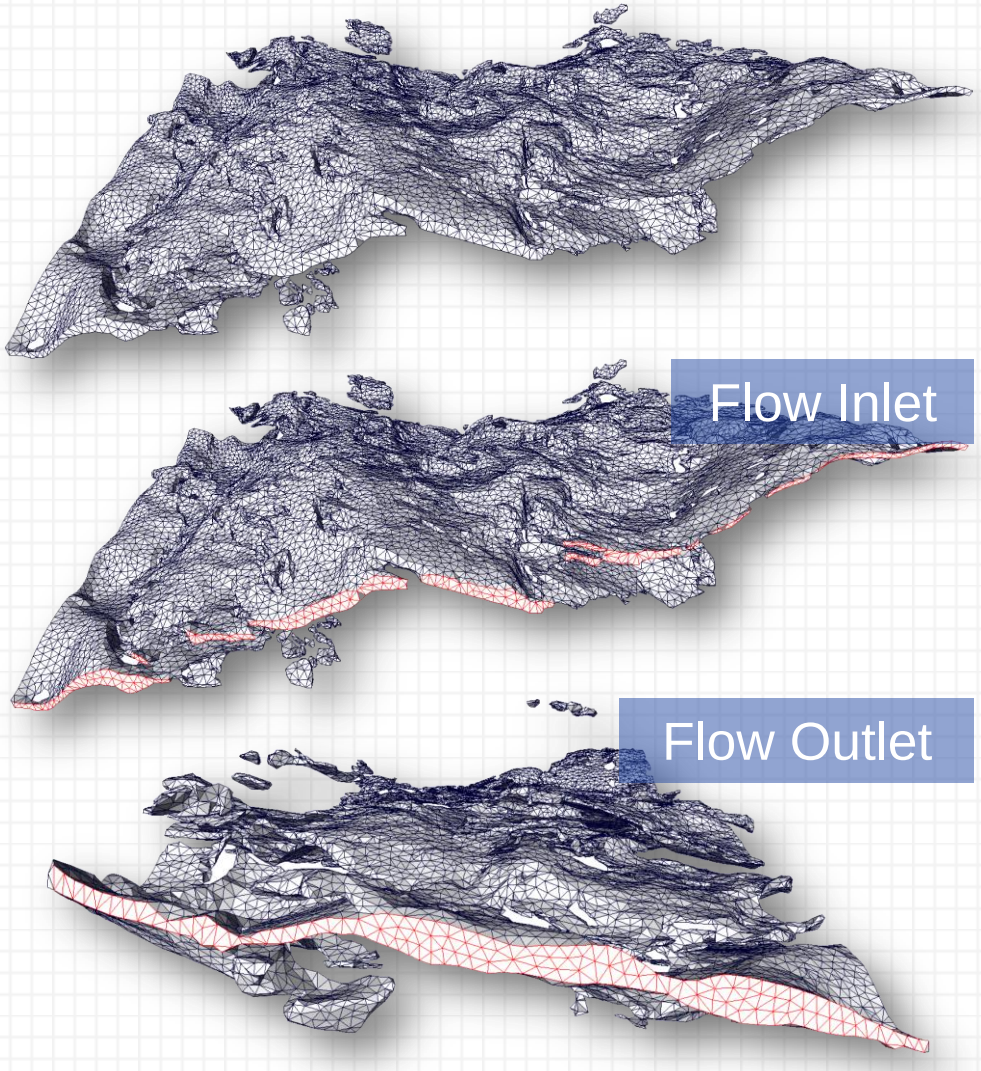
$$Kn = \frac{\lambda}{L} \qquad \lambda = \frac{k_B T}{\sqrt{2}\pi\delta^2 P}$$

(Kn)	Knudsen number
(λ)	mean free path of molecules
(L)	pore size diameter
(k_B)	Boltzmann constant (1.38E-23)
(T)	thermodynamic temperature
(δ)	molecular diameter
(P)	pressure

Next Step: Continuum (Darcy's) Fluid Flow Modeling and Simulation

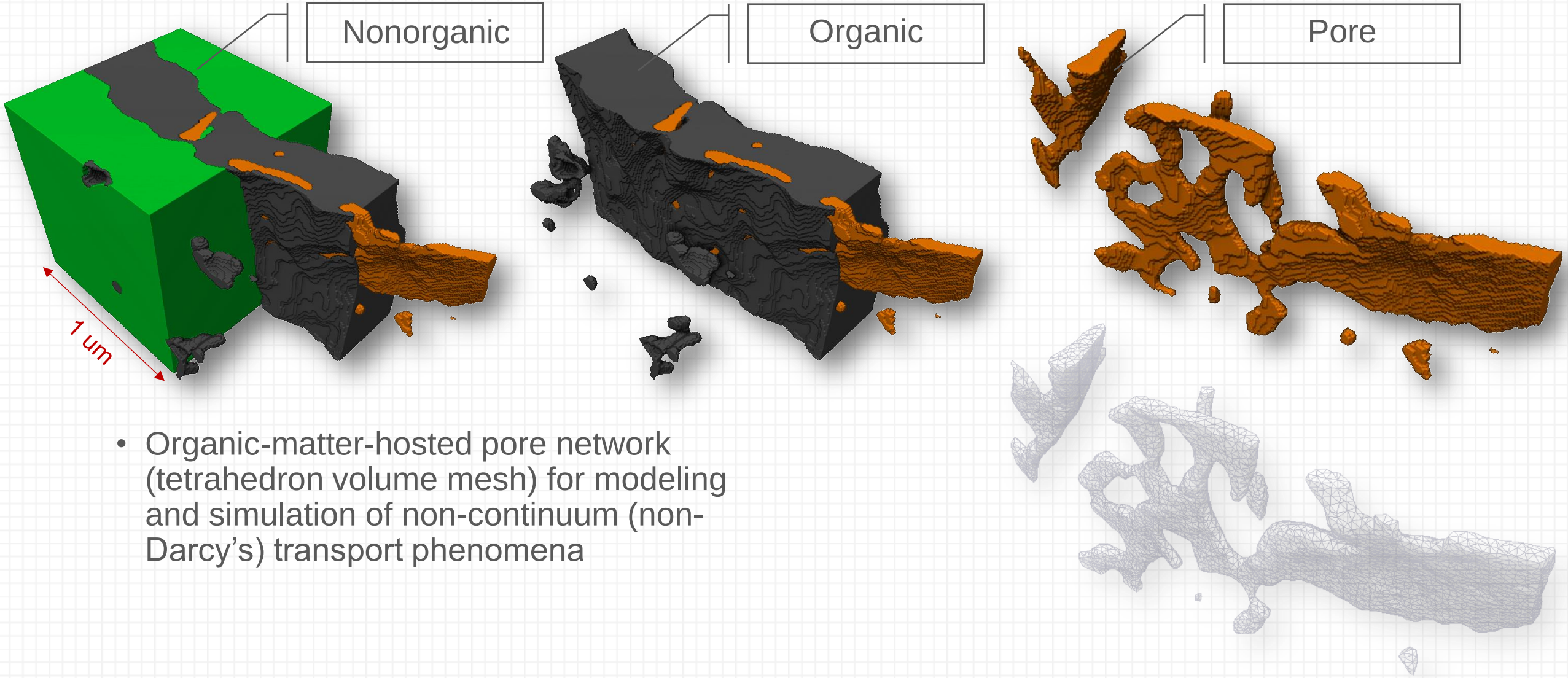


Fracture Network



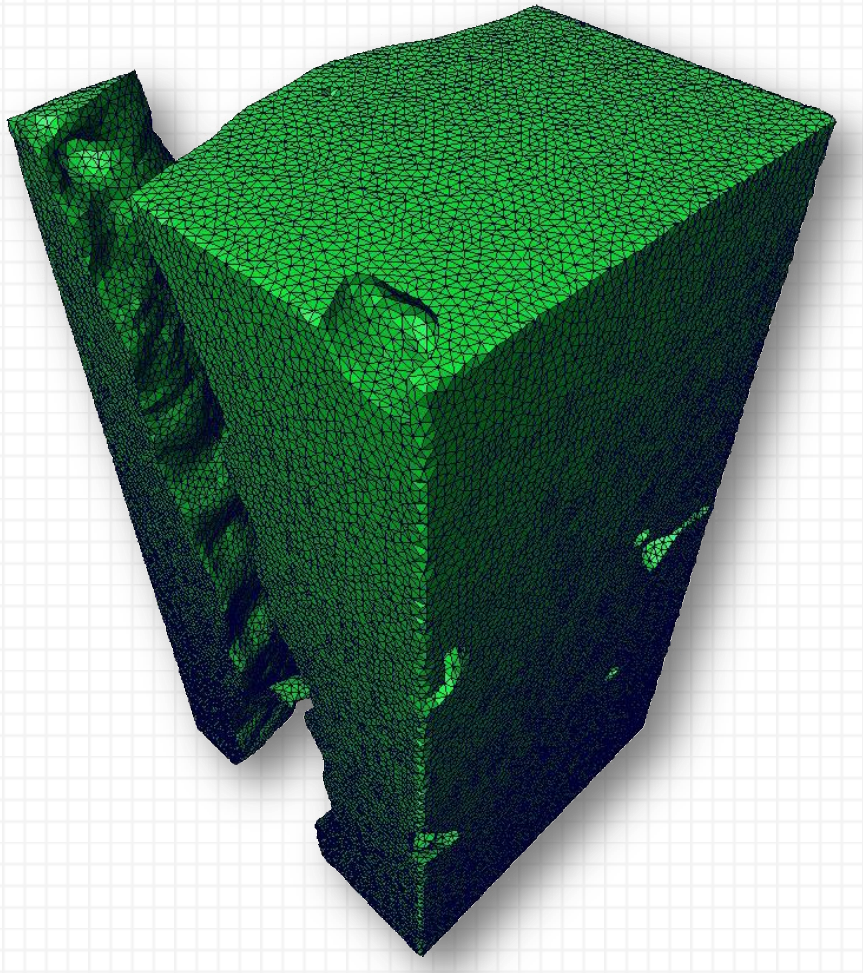
- Fracture network (tetrahedron volume mesh) for modeling and simulation of continuum (Darcy's) transport phenomena

Next Step: Non-Continuum (Non-Darcy's) Fluid Flow Modeling and Simulation

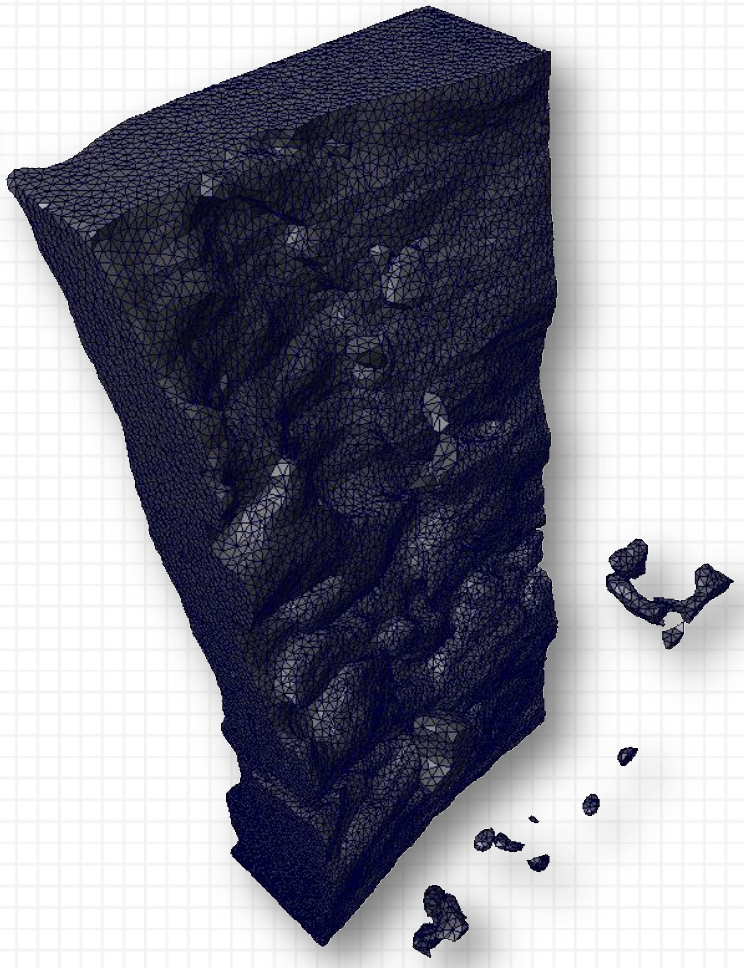


- Organic-matter-hosted pore network (tetrahedron volume mesh) for modeling and simulation of non-continuum (non-Darcy's) transport phenomena

Next Step: Non-Continuum (Non-Darcy's) Fluid Flow Modeling and Simulation



Nonorganic Matter
3D Mesh



Organic Matter
3D Mesh

Pore Network
3D Mesh

Conclusions

- Increased interest in shale reservoir characterization has sparked development of novel approaches to reservoir analysis, incorporating many modern imaging instruments and powerful modeling, simulation, and visualization techniques.
- Because the success of unconventional oil and gas development is highly dependent on understanding the effect of matrix morphology and its properties on transport phenomena over multiple scales in the shale rock reservoirs, core measurements should occur at the front end of formation evaluation.
- This study presents a multi-scale workflow that provides a high-fidelity characterization platform for studying the shale matrix structure.
- Furthermore, the workflow provides a foundation for future modeling and simulation studies of complex transport phenomena in the heterogeneous nanoporous geomedia.
- This will subsequently lead to a more complete understanding of changes in reservoir fluid distribution across the full reservoir life cycle, and significantly reduce uncertainty about the direction and extent of the fluid migration.

Thank You
Q&A

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